national accelerator laboratory

EXP-24

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ACCELERATOR EXPERIMENT--Beam Emittance Measurement

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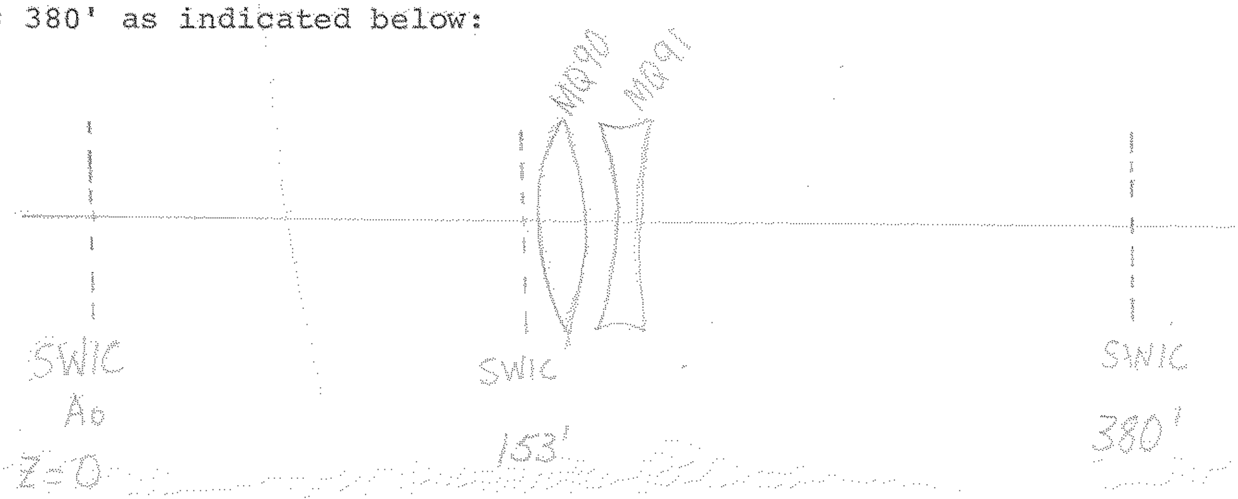
A preliminary measurement of the emittance was made for the 300 GeV/c extracted beam on 4 August 1972. The purpose of the measurement was to obtain information about the beam and to test the feasibility of the measurement method.

Running conditions were as follows:

Machine energy:	300 GeV
Machine intensity:	$\sim 3(10)^{10}$ protons/pulse
Extracted intensity:	$\sim 1.5(10)^{10}$ protons/pulse
Extraction efficiency:	$\lesssim 50\%$
Position bump:	$T_1 = 4.42$, SL = 1.6, $A_2 = 4.8$
Angle bump:	$T_1 = 4.42$, SL = 1.6, $A_2 = 1$
Pinger (air core magnet) voltages	F34 = 15 kV, F38 = 14.5 kV

Pinger timing was synchronized to A_0BIM to within ±2 μsec

Two SWIC profile monitors and the lenses formed by MQ90 and MQ91, the first quads external to the machine, were used in the measurement. One SWIC is installed immediately upstream from MQ90, Z = 153', and the other is installed at the upstream end of the B enclosure, Z ≈ 380' as indicated below:



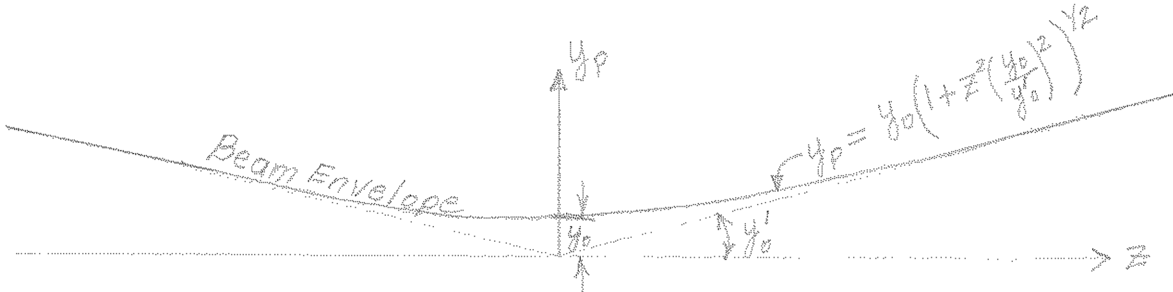
THEORY

The phase space is defined as follows:

$$\varepsilon_y = y_o \, y_o'$$

$$\varepsilon_x = x_o \, x_o'$$

where $\pi\varepsilon$ is the area of the right ellipse at the waist with axis y_o and y_o', or x_o and x_o'; y and x correspond to vertical and horizontal, respectively; y_o and x_o are the semiwidths of the beam at the waist; y_o' and x_o' are the slopes of the asymptotes to the hyperbola formed by the beam envelope as indicated below:

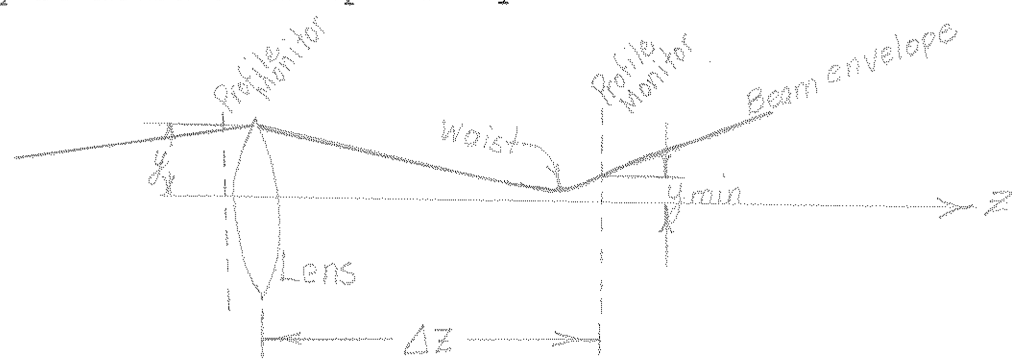


According to Banford,[1] if a lens is adjusted to obtain a downstream minimum beam size as indicated below, then the following relationship applies for the phase space:

$$\varepsilon_y = \frac{y \; y_{min}}{\Delta Z}$$

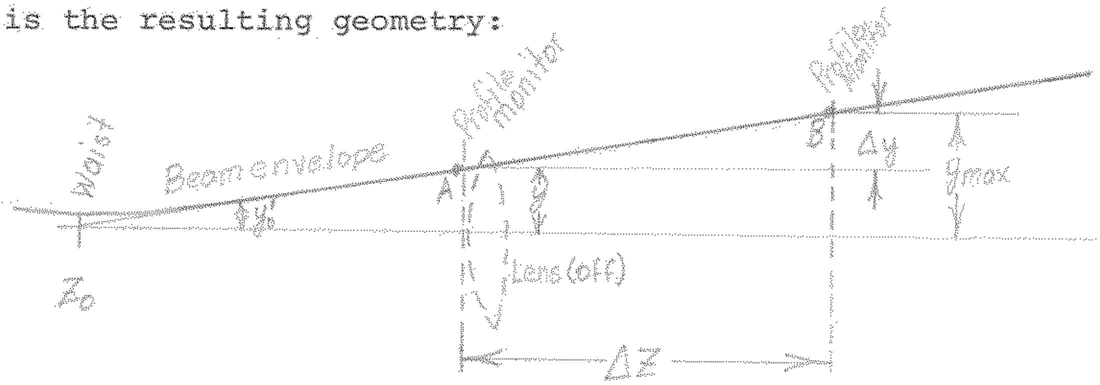
where y = the beam semiwidth at the lens, y_{min} = the minimum beam size at the downstream location, and ΔZ = the distance between the lens and beam minimum.

A similar expression exists for the horizontal phase space which may be measured independently.



It is interesting to note that a minimum beam size at a given location requires, in general, an upstream waist of a smaller dimension as indicated in the above diagram.[1]

It is further noted that the same two profile monitors yield the divergence of the beam and the location of an assumed waist upstream from the lens, if the lens is off and if both profile monitors are sufficiently removed from a waist. The following is the resulting geometry:



Clearly, if a waist is far away, $\frac{\Delta y}{\Delta z} = y_o'$, and the extension of line AB to the Z axis locates the waist. Since y_o' is known, the semi-width of the beam, y_o, at the waist can be determined from $y_o = \varepsilon_y / y_o'$, and the emittance phase space ellipse is uniquely defined. The value obtained for y_o serves also as a consistency check of the measurement since this value must be less than y measured at the lens.

RESULTS

Measured Beam Profiles (Full Size)

153' Location	380' Location	
$2y = 1.2 \pm 0.1$ mm	$2y_{min} = 2.0 \pm 0.15$ mm	
$2x = 3.0 \pm 0.2$ mm	$2x_{min} = 3.0 \pm 0.2$ mm	
	$2y_{max} = 3.0 \pm 0.2$ mm	Quads off
	$2x_{max} = 4.0 \pm 0.2$ mm	Quads off

$\Delta Z = 227' = 69189$ mm

Vertical Calculations

$$\varepsilon_y = \frac{y\ y_{min}}{\Delta Z} = \frac{(0.6)(1)\,mm^2}{69189\ mm} = (8.7 \pm 2.1) \times 10^{-3}\ mm\ mrad$$

$$y_o' = \frac{y_{max} - y}{\Delta Z} = \frac{0.9\ mm}{69189\ mm} = (13 \pm 4) \times 10^{-6}\ rad$$

Waist location $Z_{oy} = 153' - \frac{y}{y'} = 153' - (150' \pm 60') = (3' \pm 60')$ from A_o

$$y_o = \frac{\varepsilon_y}{y_o'} = (0.7 \pm 0.3)\ mm$$

Horizontal Calculations

$$\varepsilon_x = \frac{x\ x_{min}}{\Delta Z} = \frac{(1.5)(1.5)\ mm^2}{69189\ mm} = (3.3 \pm 0.7) \times 10^{-2}\ mm\ mrad$$

$$x_o' = \frac{x_{max} - x}{\Delta Z} = \frac{0.5}{69189} = (7.2 \pm 5.7) \times 10^{-6}\ rad$$

$$Z_{ox} = 153' - \frac{x}{x'} = 153' - (678' \pm 545') = (-525' \pm 545)'$$
from A_o

$$x_o = \frac{\varepsilon_x}{x_o'} = \frac{3.25(10)^{-5}\ mm\ rad}{7.23(10)^{-6}\ rad} = (4.5 \pm 3.6)\ mm\ half\ width$$

DISCUSSION

The vertical emittance appears to be reasonably consistent since the waist size calculated is approximately the same as the size of the beam at the first lens. A measurement of the vertical beam size with an existing SWIC at A_o also agrees.

The horizontal measurement is less accurate. A calculated waist of 4.5 mm half width is inconsistently large although the error is also large. This inconsistency may be resolved by a more accurate measurement and one in which a clear minimum horizontal beam size is achieved at the downstream profile monitor. This requires more horizontal focussing strength than we were able to obtain with the MQ90-91 doublet. We propose to gain the necessary focussing strength by shorting the MQ91.

The addition of another profile monitor located approximately 200' downstream in the B enclosure will provide a more accurate divergence measurement and provide desirable redundancy in our measurements. More resolution is required in the measurement and SWIC's with 0.5 mm wire spacing are proposed.

CONCLUSIONS

Although these results

$$\varepsilon_H = (3.3 \pm 0.7) \times 10^{-2} \text{ mm mrad}$$

and

$$\varepsilon_V = (8.7 \pm 2.1) \times 10^{-3} \text{ mm mrad}$$

must be considered preliminary, the measured emittances are significantly less than the values

$$\varepsilon_H = 0.23 \text{ mm mrad}$$

and

$$\varepsilon_V = 0.09 \text{ mm mrad}$$

predicted for 200 GeV/c by Rode, et.al.[2] The low extraction efficiency of only 50% and the low machine intensity may be a partial explanation. With further refinements in measurement technique and facilities, extraction parameters may be optimized and studied as a useful adjunct to accelerator research and operation.

References

1. Banford, A.P., "The Transport of Charged Particle Beams," E & FN Spon. (1966) p. 29.

2. Rode, C.H. et.al., "Design of the Slow Extracted Beam and Proton Beam Lines," 1971 Particle Accelerator Conference, IEEE Trans. Nucl.Sci., June (1971) p. 984.

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